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No. 807.

NOTES ON PORTLAND CEMENT CONCRETE.

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WITH DISCUSSION.

A number of years ago the Society of German Portland Cement Manufacturers published an article claiming that good Portland cement could not be improved by admixtures. It seems likely that the purpose of that article must have been to counteract any endeavor by dishonest men to add poor admixtures, and thus lower the reputation of German Portland cement, which then had begun to invade the markets of the world. It is also possible that experiments with many cements made before that time would not show the advantage of fine silicious admixtures, as well as the present high-limed and high-testing cements. Besides it may also be that both good and valueless admixtures were treated under one head, and therefore condemned.

It is worth mentioning that although the use of hydraulic mortars is very old, and a thorough knowledge of the nature of setting and hardening is very important, it was not until recently that much

had been done in this line. Whenever failures in concrete works were reported, they were attributed either to poor workmanship in the construction or to bad cement, while in reality neither was the cause. A cement was regarded bad when it contained, through careless manufacture, too much free lime, magnesia or sulphuric acid. The harmful effect of free lime has always been well enough known, but there is at the present day, with improved machinery and methods of manufacture, no excuse for such free lime, and it is not often met with in practice. An amount of magnesia above 1½% was long regarded dangerous, and even to-day there are many specifications calling for a cement with less than 2% magnesia. The German manufacturers, to whom this magnesia question has been of most importance, have discussed it in their meetings and in their papers for a long time. The result is that to-day 3% of magnesia in Portland cement is thought harmless, and many claim that even 5% ought to be allowed. It seems to the author that this difference of opinion has resulted not so much from the different amounts of magnesia in the cement as from the excess, more or less, of basic constituents, such as lime, magnesia and alkalies. Sulphuric acid has been considered harmless in Portland cement only to the amount of 1 to 1½ per cent. A closer investigation of the effect of sulphates in concrete was first made by Messrs. Erdmenger, Candlot and Michaëlis.* The results are, in short, that the amounts of alumina play an important part, and that it is of material difference whether the sulphates are added before or after burning. If they are intimately mixed with the raw materials a considerable quantity may not only be allowed in the cement, but is beneficial.

The author does not believe that consumers run much risk from any of the previously mentioned causes of faulty cements, because there are very few cements that contain an excess of free lime, magnesia or sulphuric acid, and if such should be the case, ordinary tests in cold water would in a few days show the bad effects of sulphates, a simple analysis would give the amount of magnesia, and a 28 days' cold-water test or a few days in hot water would show the free lime. The principal danger in concrete construction has nothing to do with the above-mentioned causes, but comes from using high-grade, well-manufactured cements, in which an extreme fineness in the grinding of raw materials

* See *Thonindustrie Zeitung*, 1891, p. 925; and Candlot's work, entitled "Cements et Chaux Hydrauliques," 1891, pp. 243, 263.

and of the finished products together with a uniform, hard burning, enables the manufacturers to increase the amount of the basic elements to a maximum without getting an appreciable amount of free lime. Such a cement will, in a short time, obtain a very high degree of strength and give excellent satisfaction wherever used in air or away from the continual action of water. For such work it may take more sand and make a more durable concrete than the old-fashioned low-limed and coarsely ground cements. It is different, however, where the concrete is to be used under water, be it fresh or salt. Then high-limed, high-grade cements will not only prove inferior but dangerous, especially if the water is rich in sulphates,‡ as shown in Table No. 1.

TABLE No. 1.—Tensile Strength.

Cement Sample.	Pat Test.		Fineness, Residue on—		Neat Cement.					1 Cement to 4 Sand.				
	Cold.	Hot.	50 mesh.	100 mesh.	7 days.	28 days.	6 months.	1 year.	2 years.	7 days.	28 days.	6 months.	1 year.	2 years.
a	Good.	Good	1.0	6.0	528	731	752	797	854	133	160	249	263	185*
b	"	"	1.0	6.0	563	785	806	803	956	108	173	192	143*	000*
c	"	"	4.0	14.5	422	547	664	730	851†	80	114	131	128	103*
d	"	"	6.5	19.5	528	692	730	752	813	90	119	172	151*	19*
e	"	"	2.5	18.0	396	572	740	795	774†	71	117	151	154	107*
f	"	Loose from glass.	4.0	19.5	481	579	802	853	970	62	113	219	233	184
g	"	Good.	6.0	23.0	563	696	821	884	955	59	108	218	256	266
h	"	"	5.0	21.0	364	502	804	912	923	40	96	197	216	194
i	Surface scaled off	"	4.0	18.0	349	541	876	831	835	32	105	200	226	238

* These briquettes were cracked very much.
† " " " " at the corners.

Each of the tests in this table, with the exception of those for two years, is an average of five breakings. The two-year tests in this table and all the tests given in the remaining tables are each an average of three breakings. In order to make comparison easier, decimals have been omitted. The same sand was used for all the tests; it was passed through a 16-mesh and retained on a 20-mesh sieve. All briquettes were made by hand, and such amounts of water used as would give the best results with each individual cement.

The water used, both for gauging and immersion, was well water, containing in one liter:

‡ See also *Thonind. Zeitg.*, 1896, No. 25; article by Dr. Stutzer.

$Ca\,S\,O_4$, 1.0214 grams.
$Mg\,S\,O_4$, 0.2238 "
Na Cl, 0.1515 "

Samples *a*, *b* and *e* were German Portland cement, *c* was Belgian, and *d* English; *f*, *g*, *h* and *i* were samples of an American Portland cement. Samples *e* and *i* had been kept in the laboratory about 18 months, and were somewhat lumpy; the others seemed comparatively fresh and in the best condition.

It becomes apparent from an inspection of the sand tests in Table No. 1, that those briquettes which broke the highest in a short time fared worst in the long run, and analysis shows that those cements contain more basic elements, lime and magnesia, in proportion to acid elements, silica, alumina and oxide of iron, than the other samples.

It has long been evident to the author that under the hardening of cement mortar a part of the lime is continually set free or separated from its molecular combination with silica, alumina or iron; in other words, these last substances are able to combine with more lime and magnesia in a dehydrated state in the kilns than in a hydrated state in the mortar. Dr. Michaëlis* finds that about 33% of the hydrate of lime in the average Portland cement is set free and will seek other material to combine with. If reached by the air it will take up carbonic acid and form a carbonate, which does not injure the concrete; in pure water it will be washed away in the water, and the concrete will be left more porous and weaker; in sea-water, or water containing mineral salts, these salts will combine with the calcium hydrate and form voluminous double salts, which will swell and destroy the concrete. Mr. Gerhart Herfeldt discusses this same subject, and shows, like Dr. Michaëlis, how Portland cement can be improved by admixture of trass, but his tests cover somewhat too short a time to show the advantages of the admixture fully.

The author has often noticed that unwashed sand would give better tests than well washed and cleaned sand, and he can account for it only in this way, that the fine-clay substance in the sand is able to combine with the liberated lime-hydrate in the cement. It was this circumstance which first gave him the idea of improving concrete by adding a certain quantity of fine silicious materials; and experiments

*In an excellent article entitled "Das Verhalten des hydraulischen Bindemittel zum Meerwasser," published in *Verhandlungen des Vereins zur Beförderung des Gewerbfleisses*, 1896, Nos. 6 and 7.

made subsequently more than satisfies him of the correctness of his first supposition. Out of many tests, more or less systematically carried on, the results of a few, which agree in everything with the others, are given in Tables Nos. 2 and 3.

TABLE No. 2.

	Neat cement.	1 part cement, 3 parts sand, water 12%.	1 part cement, 1 part sil. 3 parts sand, water 14%.
7 days	419	77	33
28 "	554	136	100
6 months	847	264	341
11 "	950	298	470
2 years			582

TABLE No. 3.

	Neat cement.	1 cement. 2,5 sand. water 12%	1 cement. 1 sil. 5 sand. water 12.8%
7 days	507	89	40
28 "	685	163	125
4 months	911	252	314
11 "	917	254	374

Table No. 4 shows the compression tests in pounds per square inch.

TABLE No. 4.—Compressive Strength, Pounds Per Square Inch.

	German Portland Cement.		American Portland Cement.	
	1 cement. 4 sand.	1 cement. 1 sil. 8 sand.	1 cement. 4 sand.	1 cement. 1 sil. 8 sand.
7 days	445	218	282	167
28 "	776	441	603	320
80 "	1 047	700	945	558
6 months	306	901	1 094	805
12 "	.....	1 518	1 403	1 409
1 day in air 36 days " cold water 10 " " boiler with pressure between 20 and 90 lbs.	836	more than 2 030*	1 846	1 804

* The testing machine could break only as high as 2 030 lbs.

Table No. 5 shows the results of varying proportions of cement and silicious material. Cement *A* is American, and cement *G* is German, the same as *a* in Table No. 1.

TABLE No. 5.—Results of Varying the Proportions of the Ingredients.

	Neat Cement.		2 Cement. 1 Sil.	1 Cement. 1 Sil.		1 Cement. 2 Sil.	2 Cement. 6 Sand.		2 Cement. 1 Sil. 9 Sand.	1 Cement. 1 Sil. 6 Sand.		1 Cement 2 Sil. 9 Sand.
	A.	*G.*	*A.*	*A.*	*G.*	*A.*	A_1	G_1	*A.*	A_2	G_2	*A.*
7 days	464	566	233	95	147	42	129	185	55	27	52	Too poor to break.
28 "	601	800	284	154	243	84	183	223	115	92	92	76
80 "							248	215	181	151	131	141
6 months			513	373	504	262	293	294	256	213	218	175
12 "	882	891	683	546	613	474	366	287	414	422	415	404
							*436	*287		*292	*305	

* 1 day in air; 10 days in cold water; 10 days in boiler with a pressure between 20 and 90 lbs. per inch.

Fig. 1 shows A_1, G_1, A_2 and G_2 graphically.

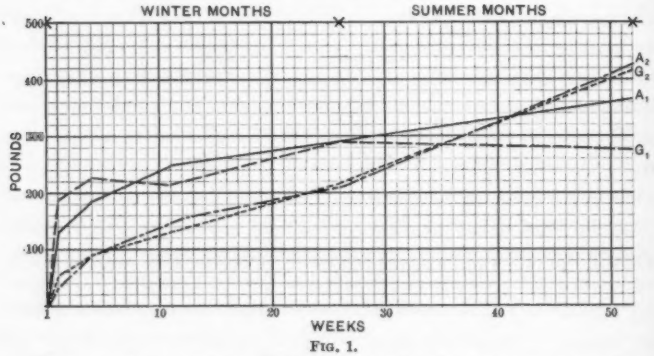

Fig. 1.

Such are the author's results invariably with silicious admixtures with Portland cements. What in the above experiments is called sil is a volcanic ash found in great quantities in Nebraska, Colorado, and other places. Its chemical composition is very similar to that of Santorin earth from Greece and trass from Germany. The analysis of the sample used for most of his experiments he found to be:

Silica	71.78
Titanic acid	0.80
Alumina	12.71
Oxide of iron	2.29
Magnesia	0.35
Lime	1.01
Water of composition	4.52
Alkalies (by difference)	6.54
	100.00

The composition varies, however, in the different localities and possibly at different depths in each deposit. Dr. Erdmenger found in a sample sent him from another locality:

Silica	74.28
Alumina and oxide of iron	13.80
Magnesia	Trace.
Lime	0.09
Oxide of sodium	1.87
" potassium	3.90
Loss by ignition	4.50
Undetermined residue	1.23
	99.67

Such ashes as contain the most chemically bound water are considered best for cement admixtures, although the author believes that in a long run there will not be much difference.

As a rule such ashes are found in layers from 5 to 10 ft. deep, but the author is told that in Colorado much thicker layers are found. In the banks it is somewhat moist and can be shoveled out easily; when dry, part of it will be lumpy, especially the more impure varieties. Squeezed out, it will have less than 1% residue on a 100-mesh sieve. The color is either gray or white, the gray being the cleanest, but coarsest. It is believed to originate from volcanic eruption; being carried by the wind, it would settle in small quiet lakes, which would fill up, solidify and afterwards be covered with dirt.

Such volcanic ashes and similar material, like trass and pozzolana, have been used with hydraulic limes for water mortars far back in history; thus Smeaton used them in the Eddystone Lighthouse in 1756–59. The author does not know, however, that they have been used to any extent with Portland cement.

Where such ashes, trass or pozzolana cannot be had at a reasonable price, other materials may be used. Waste products from alum factories and certain silicious slags are said to give very good results. Certain kinds of clay and sand when ground extremely fine will also give good satisfaction. It is the author's experience that sand and cement ground together (sand cement) will give higher tests in a short time than when the cement and sand are ground separately and mixed afterwards, but in a long-time test it does not seem to make any difference. How powerful such fine silicious material is in combining with

free lime can best be seen by adding increasing amounts of unslacked or partially slacked lime to Portland cement, and then making briquettes with and without the silicious admixture. Table No. 6 contains results of such tests, and Fig. 2 is a diagram of the same data.

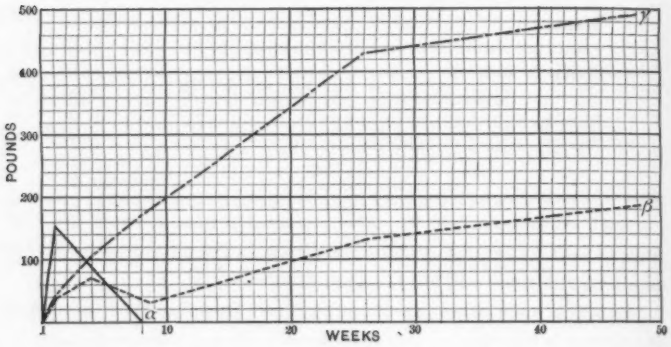

FIG. 2.

TABLE No. 6.

	1 cement, 0.5 partially slacked lime, 4 sand. α	1 cement, 0.5 partially slacked lime, 8 sand, 1 il. β	1 cement, 0.2 partially slacked lime, 6 sand, 1 sil. γ
7 days....	154	36	41
28 "	88	64	107
60 "	Fallen to pieces.	37	174
180 "	.....	132	435
330 "	.....	168	492

It is here specially interesting to study the middle column of the tests, β. It will be seen that while the destructive force of the free lime makes itself more and more prominent in the first 60 days, in which time the briquettes in column α are entirely destroyed, the briquettes column in β, while weakened somewhat, are able to regain strength and act like sound concrete, showing that the expansive force of the lime has been overcome. Column γ shows a steady and uniform increase, which indicates the perfect soundness of the concrete from the start.

DISCUSSION.

GEORGE W. TILLSON, M. Am. Soc. C. E.—The author states that all briquettes for the tests summarized in Table No. 1 were made by hand, and such amounts of water used as would give the best results with each individual cement. While engineers usually specify the maximum amount of water to be used in making briquettes, generally from 10% to 15%, according as the cements are tested neat or with sand, it is a fact that different cements require different amounts of water in order to bring out the full strength of each brand. It is perfectly well known, however, that it is impossible to prevent workmen from using an excess of water, no matter how careful the inspection may be. In making tests of cement for any particular work, the conditions should be nearly or quite the same as those under which the cement will be used, or each cement should be handled so as to bring out its maximum strength. It is unfair to classify cements according to the amount of water used in testing, when proportionately greater amounts may be used in the work. Hence the action of the author in using the amount of water which each brand of cement requires is particularly commendable. Mr. Tillson.

It will be seen in Table No. 1 that the greatest strength developed by any cement in the two-year neat tests was 970 lbs., while the same cement mixed with sand gave but 184 lbs. at the expiration of the same period, the lowest result of any of the samples which were perfect and almost the lowest of all those tested. The last sample in the table, which showed a low neat strength at the end of two years, had the second highest strength in the mortar at the end of that time. Experiments of a somewhat similar character were made by the speaker in a western city in order to establish a standard of the various cements used there. Soon after the tests were begun, the Board of Public Works and the speaker rejected for the coming year certain cements which had been used previously, and adopted others. The agents of the rejected brands appealed to the Common Council, and the latter began an investigation. The briquettes for the tests which were in progress at the time were made with such variable proportions of water as the tester had found adapted to bring out the greatest strength of each brand. The investigation began at the time of the breaking of briquettes ninety days old. The neat tests indicated that the rejected cements were stronger than those brands which were retained, and that their strength was increasing, but the mortar tests proved that the rejected cements were inferior when mixed with sand and decreasing steadily in strength. Subsequent experience with actual work confirmed the course taken in the matter and the result of the tests. It is evident that neat tests of unknown brands of cement are of doubtful utility in determining their actual value.

Mr. Goldmark. HENRY GOLDMARK, M. Am. Soc. C. E.—The subject of cement specifications, particularly the simplification of such specifications, is very important. In building bridge abutments and other concrete masses in which great strength was unnecessary, in the Rocky Mountain region, the speaker had to obtain his cement from San Francisco. It was carried by water to that port, and then shipped by rail about 1 000 miles to its destination. The matter of tests was important, because the cement could not be tested at the seaboard, and it was necessary to await its arrival on the work before examining it. The rejection of many carloads after such a long haul was a serious matter; fortunately the careful tests which were made gave good results. It required much consideration to determine on the course to be followed in case the results were not exactly in accord with the specifications, and it appeared wise to limit the orders to a few well-known brands which the engineers connected with the work had found entirely satisfactory and reliable after an experience of a number of years. It was found advantageous to retain in the concrete rock the small fragments of stone usually screened out; the material was of course well cleaned.

During the progress of the work some slag cements were sent to the engineers. Tests made with them indicated that they have a greater strength at the end of seven days than would be expected, but the increase in strength from seven to twenty-eight days was very small, and finally seemed to cease, and the strength to decrease, if anything. The speaker did not care to speak positively about this matter, as he was present during the beginning of the tests only.

Mr. Lesley. R. W. LESLEY, Assoc. Am. Soc. C. E.—The paper alludes to the danger of using high-limed Portland cements in salt water, and the necessity of adding a silicious material to the cement in order to enable it to resist such water. While Aspdin's patent on Portland cement was taken out in England in 1824, it was not until about 1840 that the manufacture became commercially successful there. This was followed by other works established in Germany and in Belgium a few years later. All of the original Portland cements were made with moderate percentages of lime, as compared with the percentages of silica and alumina, and for many years the manufacturers continued to produce cement in a perfectly safe manner, in order to obviate any danger that might arise from an excess of lime. Up to the time of the construction of the London main drainage works, the first undertaking in which great quantities of Portland cement were used, most requirements were satisfied by moderate results of neat tests made after seven days, and the two papers of Mr. John Grant,* show that with these moderate tests, excellent results were obtained up to very long periods.

For a number of years the manufacture of cement went on in the

* See *Proceedings* of the Institution of Civil Engineers, Vol. xxv, p. 66; Vol. xxxii, p. 266.

line indicated by the tests of Mr. Grant, but within the past ten years the requirements have been gradually changing, the tendency being to increase the fineness of the product on the one hand, and to increase the tensile strength of the neat cement at the end of seven days on the other hand. These two things, from the manufacturers' as well as from the engineers' point of view, are absolutely irreconcilable. The same Portland cement clinker, taken from the kiln and ground to a fineness of 90% on a 10 000-mesh sieve, will give a lower tensile strain in neat tests at seven days than if ground to a fineness of 75% to 80% on the same sieve. The obvious result of the tendency toward specifications requiring on the one hand very great fineness and requiring on the other hand very great tensile strength in neat tests, has been to lead the producers of cement toward the danger line, so far as the ultimate safety of the product is concerned. In order to accomplish the desired result indicated by the divergent elements of these latter specifications, the proportion of lime in the cement was increased 3% or 4%, a process just as simple as adding more clay to the material to run it up in the elements of silica and alumina, and costing the manufacturer no more. The cement was then ground very fine and passed all the specified tests. Meanwhile, however, specifications were still being raised, and the irreconcilable elements of seven-day neat tests and extraordinary fine grinding still further increased. This entailed still higher lime, and the discovery was made that this overlimed Portland cement would sometimes crack at short periods, and sometimes go to pieces at long periods. To meet this condition of affairs, which certain engineers alleged ordinary cold-water tests were unable to detect, many new tests were proposed, such as boiling, hot water, hot air, steaming and other similar violent methods, which it was claimed would discover the presence of an excess of free lime. Then the manufacturers were forced to devise some method of satisfying these three conflicting requirements. Gypsum or sulphate of lime in its crude or calcined condition is about as cheap as most of the materials, which, in the ordinary course of manufacture, ought to enter into cement, and it was soon found that when a small percentage of this material was added to the cement after calcination, that the fineness, the high seven-day neat test, and the boiling test could be easily met, and by tables which the speaker had occasion to refer to before this Society some years ago,* it was shown distinctly that every cement which was high in sulphuric acid and high in lime, passed the boiling tests and the other requirements of the high specifications. The outcome is that a man as distinguished as Dr. Michaëlis, in his recent writing on the subject, finds that cements laid in sea water prior to the increase in neat tests stood and are still standing without a complaint against them. Of late years, however, there has been the

Mr. Lesley.

* See *Transactions*, Vol. xxxii, p. 332.

Mr. Lesley. failure of the Aberdeen Docks, as well as similar failures of sea works laid in Portland cement, to which he refers. In reply to Dr. Michaëlis, the German Society of Portland Cement Manufacturers cites in support of the fact that Portland cement does endure in salt water, works laid as far back as 1840, where the character of the cement was very different from the character of the Portland cement made to meet the abnormally high neat specifications of the present day.

Broadly speaking, therefore, the recent failures of Portland cement in salt water were due to no defect in cement unknown to the men who first made the material, but were due to recent specifications and requirements absolutely beyond any strain that would be put upon cement. The results of the work executed in sea water within the last ten years and criticised by Dr. Michaëlis are precisely those which the people who have interest in the successful manufacture, introduction and use of Portland cement for all kinds and all character of work are compelled to disown absolutely.

The high and conflicting requirements have, to the speaker's mind, produced a condition of disease, and it would seem to him that had the author proposed a return to old methods of manufacture, old modes and kinds of tests, and to the old and well-established landmarks, he would have accomplished a more permanent result than by temporizing with the matter by adding sil or other infusorial earth to overcome a condition that should never have existed.

Trass, as proposed by Dr. Michaëlis, and sil, as suggested by the author, are not the only materials which, when ground with cement or mixed with it in a powdered condition, improve it and increase its temporary strength. At Malta, a series of tests by British army engineers show the addition of ground limestone to give better results than ground granite, and at Lafayette College some recent experiments by students there show similar results by the addition of fine screened dolomitic limestone to concrete. In these last experiments it was also indicated that in making concrete without separating the dolomitic limestone screenings from the broken stone, the concrete was stronger than when sand, clean stone and cement were mixed together.

The author states that he mixes the silicious material, stone and cement with 14% of water. The silicious material, commonly called infusorial earth, has the following composition:

Soluble silica	75.97%
Alumina	2.37%

Some experiments were made by Frederick H. Lewis, M. Am. Soc. C. E., with this material, and the following results were obtained.

When dry, 300% of water is needed to mix it neat. When mixed 100 cement to 40 infusorial earth, the mixture takes 100% of water to make briquettes, while the ordinary Portland cement takes only 22%

of water. When mixed, 100 cement to 40 infusorial earth to 420 sand, 30 parts of water are required. Mr. Lesley.

	Weight.	Tensile strength.
Neat cement mixture.....	160 grams.	650 pounds.
Cement, 100; infusorial earth, 40..	62 "	52 "
3 Sand to 1 cement.....	138 "	240 "
42 Sand, 10 cement, 4 infusorial earth.....	108 "	40* "

The result of this would indicate that if infusorial earth was used and represents the sil referred to by the author, his percentages of water differ materially from those obtained by Mr. Lewis.

The main point that the speaker desired to make in summing up is that if manufacturers were not forced to meet very high and conflicting requirements, engineers would use the same grade of cement that has won the confidence of everybody, and led people to consider concrete as good as stone, it would be a much simpler matter to continue furnishing the same cement, and retain its high character, than it is under some of the more recent specifications.

Large quantities of slag cement, mentioned by Mr. Goldmark, were made in Germany about 1885. Investigations of the process and the product in this country had much the same results as he mentioned; the results of long-time tests were failures. A United States Consular Report† states that out of about fifty slag cement works in Germany in 1890, only two were then in operation, from which fact the growth of the industry in America can be predicted. The chemical difficulty of the process is the presence of sulphides in slags, and until some reliable method of dealing with them is devised, no good uniform slag cement will be made. The practical difficulty is that no one making first-class iron or steel will lay much weight on the kind of slag he is turning out, and Portland cement is too important in its uses to be dependent for its manufacture upon the production of a uniform by-product of another industry.

* Seven days.
† Dated July 3d, 1895.

CORRESPONDENCE.

Mr. Maclay.

W. W. MACLAY, M. Soc. C. E.—The paper does not make out a case against using high-grade Portland cements, which of late years have come so much into favor. The question of mixing various materials with Portland cements, both for the purpose of cheapening and also of improving them, is quite an old one, as the paper states, and has been much agitated, both in this country and abroad; but up to the present time, as the German manufacturers very justly claim, no commercial substance has been discovered, which, mixed with Portland cement, improves its strength, both in air and in water. The most that can be claimed as proved is that certain substances can be mixed with Portland cement, which cheapen it without seriously diminishing its strength, especially in the sand mixtures. This is especially true of sand or silica cement, where the sand mixtures are almost as strong as the parent Portland cement from which the silica cement was derived.

The distinction is not brought out in the paper, between mixing an additional substance with Portland cement, so that one portion of the cement is replaced by another material, and simply making an addition to Portland cement mortar. The German manufacturers say, if Portland cement is replaced by any other substance, the strength of the resulting mortars is diminished; this is also the writer's experience. On the other hand, if finely pulverized substances, such as silica, be added to a true Portland cement mortar, they may by filling up the voids, especially in the case of lean mortars like one part cement to four parts sand, cause an increase of strength. This is really a physical improvement of the mortar, and has nothing to do with the question of free lime in the Portland cement itself.

In the table it is not stated that the tests were made on briquettes immersed in water, except in conjunction with boiler pressure tests. The inference is they have been immersed, and it would be interesting to know the author's experience with mixtures of sil kept in air.

Several years ago the writer conducted an extended series of tests with trass and pozzolana mixtures, as compared with Portland mortars. The former substances are very nearly like sil in chemical composition and in the following respects:

If added to neat Portland cement, they do not improve it. If added to Portland cement mortars, they have a weakening effect at first by reason of their extreme slowness in setting, but after long periods they add strength. For instance, Table No. 5 shows that the addition of one part of sil to one part Portland cement diminishes the strength of the neat cement at 7 days to about one-fourth that of the original cement, at 28 days to about three-tenths, and at one year to about three-fourths. The same table shows that by adding one part of sil to a Portland

cement mortar of two parts cement and six parts sand, the strength of the mortar is diminished until the end of one year, when it begins to increase. In the present time, when buildings and engineering works are carried to completion so rapidly, can engineers afford to add anything to Portland cement to diminish its first strength, with the hope that in a year or two it may improve it? Mr. Maclay.

The great advantage of using a high-grade Portland cement for water work is it gets its strength so quickly that it does not experience the disintegrating effect weaker mortars suffer, and the writer cannot but think this strength is permanent.

In view of the good results of Portland cement in actual practice, engineers cannot accept too cautiously the criticisms of theoretical tests, especially when extended over long periods where liability to error is greatly multiplied. For example, the sea fortifications of Copenhagen have been built forty years and are to-day in a good state of preservation; there a Portland cement with nearly 65% of lime was used.

JOHN F. WARD, M. Am. Soc. C. E.—The reports of tests of cement, as given in this paper, are interesting as showing how very small is the reliance which can be placed on the results of short-time experiments as to the tensile strength of the cements now in general use. Table No. 1 shows that of nine samples of neat cement, the best, as shown by two years' experience, held only fifth place in the list at the end of the first seven days, being nearly 15% weaker than the cement which at that time seemed to be the best, but at the end of two years the fifth in the list rose to be first, thus proving, in this case at least, that the seven days' test was not only useless, but in a high degree misleading. Mr. Ward.

In the mortar tests in the same table the discrepancies are even greater between the short and long-time experiments, as the cement which at two years proved to be the best, at seven days was seventh in a list of nine, and one which was at the head of the list in twenty-eight days fell to the foot in two years.

The tendency for some seasons past has been to question the entire reliability of short-time tests as a guide to all of the good points of cement, and such a showing as is made in this little table ought to make any one think whether it is worth from 20% to 50% of the cost of a barrel of cement to find out what it will do in the way of hardening in a week or even in a month, when, as would appear from the results shown, that the information so obtained may be of no use whatever.

It seems rather odd to see the engineers, who are supposed to be on the lookout for deficiencies, following the lead of the manufacturers in using the most expensive apparatus and the greatest care to coax the specimens to behave well by setting up in a week, and giv-

Mr. Ward. ing a showing which the experience of a year or two may turn to ridicule.

The reason why the short-time test is so fallacious is that it is simply a record of the strength of the hydration, which is merely a temporary crystallization or solidifying of the water in the mixture, whereas the ultimate strength of the cement, which is often double that of the hydration period, comes in the shape of silicification, which is a far more perfect and permanent combination, but requires more time for its completion.

Many engineers will say that the needs of their work will not allow them even a week's time for testing their cement, but this only emphasizes the objection to short-time tests, and adds more reason to the call for something which may take the place of the common tensile breaking of briquettes.

The question comes then, in what direction to look for relief. One obvious way is to buy on reputation almost entirely, and the German manufacturers have worked hard and faithfully in this direction with such success that very large quantities of their cement are used by parties who have faith in their very elaborate and costly laboratory tests, without anything more than the slightest examination of the quality by the buyer. There are also in this country many makers whose product has been for years so uniform and well known that the engineer feels at his ease in using it, even if he is not so situated that he can make thorough tests of his own, and wait a year or two to see the results.

It seems to be the almost universal opinion that the disastrous going back of cements from their flattering short-time tests is caused by the presence of lime in a free state, or in such form as to be set free by the action of the other ingredients under the conditions to which they become exposed in use. Some authorities say that this excess of lime can be detected by tasting; but, whether this is correct or not, it would be very desirable to find some chemical reagents which, applied to minute quantities of cement, would show by change of color, ebullition or otherwise, the presence of the matter which, in the long run, would make the mortar return to the shape of loose powder.

Mr. Michaëlis. Dr. W. Michaëlis.—It gives the writer the greatest satisfaction to learn that the author has found and drawn attention to an American pozzolana, apparently identical with Santorin earth, which is also a volcanic ash, or granulated trachyte-porphyry, or triturated pumice stone. After trass, Santorin earth is the best admixture for sea mortar; it contains about 80% of hydraulic substance, and at least 60% of hydraulic silica. Such a pozzolana, dried and sifted, or ground and sifted through a No. 80 sieve, will undoubtedly make an excellent mortar in combination with high-class Portland cements and hydraulic

limes. The writer would advise a mixture of six-tenths, by weight, of Portland cement and four-tenths of the sil, although the latter will give a remarkable mortar if used in the following combination : Mr. Michaëlis.

4	parts by weight or	3	by volume of pozzolana.		
1	" "	1	" "	quicklime paste or powder of hydrate of lime.	
1.5	" "	0.5	" "	sand.	

Such a mortar contains only about one-fourth of the lime in Portland cement mortar, and is the best known at present for resisting the action of sea water. It hardens very slowly, especially at low temperatures, and if left for three or four days—even seven will not do harm—until it begins to set, it may be dropped into deep water without any danger of being washed out.

The writer recommends a mortar of Portland cement to secure the strength of this material, and enough pozzolana, rich in hydraulic silica, to bind the excess of lime which becomes free during the hardening of the cement. He would also advise American engineers to try the sil discovered by the author in the following combinations :

First.—With the best Portland cement and a low percentage of alumina.

Second.—With strong hydraulic limes.

Third.—Mixed with quicklime, as previously indicated, in strong mortar-mills. The concrete made with this mortar should have 16 parts, by volume, of broken stone, 15 parts of sil, 5 parts of quicklime paste or powder of hydrate of lime, and 2 to 3 parts of sand.

Richard L. Humphrey, Assoc. M. Am. Soc. C. E.—The paper appears to the writer to lack important detail information and data sufficient to confirm the theories advanced. Mr. Humphrey.

Concrete is defined as a mixture of two parts, the mortar of cement or lime and sand, and the aggregate, broken stone, crushed slag, gravel, etc. While admitting that mortar is the essential part of concrete, the writer is not willing to apply to concrete deductions based on mortar tests alone. In the tabulated tests in the paper it will be observed that the compositions are exclusively sand and cement.

The author states that "it becomes apparent from an inspection of the sand tests in Table No. 1, that those briquettes which broke the highest in a short time fared worst in the long run, and analysis shows that those cements contain more basic elements, lime and magnesia, in proportion to the acid elements, silica, alumina and oxide of iron, than the other samples," yet he does not present these analyses to confirm the statement. Again, in the analysis of the well water he neglects to state whether the water had an acid or alkaline reaction, which is a very important factor in considering the probable action of the salts contained in water acting on masses of cement.

The author also fails to describe the sand used in making the tests. He does not state its mineralogical nature ; whether it was a

Mr. Humphrey.

natural sand or a standard crushed quartz sand. If it was a natural sand, it is important to know whether it was a bank or a bar sand, and whether it was washed and freed from any foreign matter it may have contained before being used.

On inspection of Table No. 1, it will be noticed that there are but two of the samples which do not show a decrease in strength in the two-year tests, and it is interesting to notice that both of these cements are American brands. It has occurred to the writer that possibly the sand used in these tests may have been the cause of this decided decrease in strength. It has been his experience that where the basic elements are in excess in cement the neat tests are the first to show signs of unsoundness. In Table No. 1 it will be observed that only the sand tests show a loss of strength, and this fact seems to cast suspicion on the character of the sand used.

The writer has also found that where swelling takes place in cements, the neat briquettes, being more compact than the sand briquettes, and therefore having fewer voids, show this action more strongly. It is still less noticeable in concrete.

TABLE No. 7.—REARRANGEMENT OF TABLE No. 1.

Group.	Fineness. Residue on.		Neat Cement.					1 Cement; 4 Sand.				
	50	100	7 Das.	28 Das.	6 Mos.	1 Yr.	2 Yrs.	7 Das.	28 Das.	6 Mos.	1 Yr.	2 Yrs.
American	4.8	20.4	439	580	826	870	921	48	106	209	244	221
Belgian	4.0	14 5	422	457	664	730	851	80	114	131	128	108
English	6.5	19.5	528	692	730	752	813	90	119	172	151	19
German	1.5	10 0	496	696	766	798	862	106	150	197	187	97

The writer has arranged in Table No. 7 the tests given in Table No. 1 in groups according to the country in which the cement was manufactured, and it will be noticed that the average English Portland makes the poorest showing, the American Portland the best, and Belgian and German next. The writer has found that English cements, as a rule, are low in lime and magnesia, while American, Belgian and German cements are higher. As the analyses of the cements from which the tests in Table No. 1 were made are not given, it is impossible to carry the comparison further. It will again be noticed that the average neat tests show a uniform increase, while the sand tests show a decrease in strength at the end of one or two years.

The author has stated that the mortars which yield high tests for short periods of time showed the greatest decrease in the long time. It will be noticed on comparing the average sand tests of the English

cements with those of the German cements, that the English, while giving lower tests for short periods of time, show the greatest decrease in the long run. Mr. Humphrey.

The author does not state whether the water used for the tests recorded in Tables Nos. 2, 3 and 4 was the same as that used for those in Table No. 1. If such is the case, then the tests in those tables do not confirm the conclusions drawn from Table No. 1, as none of the tests in Tables Nos. 2, 3 and 4 show a decrease in strength.

Again, in Table No. 5, the cement marked *G* is stated to be the same as sample *a* in Table No 1. It will be noticed that there is 100 lbs. variation in the neat tests at the end of one year.

The question naturally arises, whether the tests were all made at the same time, under the same conditions and by the same person. If so, then the variation shows a decided lack of skill in making the briquettes, and that the number of briquettes were too few for obtaining a fair average.

The author infers that the addition of sil, a soluble silica, to a cement high in lime, not only prevents the tendency to lose its strength, but on the contrary produces a decided increase of strength, and then he quotes Tables Nos. 2, 3, 4 and 5 in support of this statement. Yet, on comparing the last column of Table No. 5, with the column headed A_2, it will be found, as might be expected, that the additional part of sil decreases the strength of the mortar appreciably.

It will be noticed that this sil is exceedingly fine, having a residue of only 1% on a 100-mesh sieve. It seems to the writer that this fine sil merely fills the voids of the coarser sand, and that the mixture being more dense is therefore stronger, just as a concrete made of stone of graded sizes is more compact and often stronger than one having stone of the same size.

FREDERICK H. LEWIS, M. Am. Soc. C. E.—The paper presents a question which has already been debated for fifteen years in Europe, and is now scheduled by a German commission for a series of experiments covering a still longer term. This question is whether or not Portland cement may be ameliorated by the addition of substances containing hydraulic (or soluble) silica, and it is interesting because by general consent the theory is conceded to be correct by those who declare it mischievous in practice. Mr. Lewis.

As the author's general presentation of the subject is meager and his co-ordination of the results reported with previous work somewhat unsatisfactory, a brief outline of the main argument as it now stands may be of interest, and to this the writer addresses himself.

In the opening paragraph the author writes: "A number of years ago the Society of German Portland Cement Manufacturers published an article claiming that good Portland cement could not be improved by admixtures." While the reference is not explicit, there can be

Mr. Lewis. little doubt that he has in mind the communication of the German association to the Prussian Minister of Public Works in 1882. This reads as follows:

"Normal Portland cements do not require a so-called improving addition; such an addition produces rather a decrease of strength which is nearly proportionate to the amount of the addition"; and further, "The Council is unfortunately of the opinion that the means of coercion which the factories, desiring to furnish for the future an unadulterated article, have at hand, are not sufficient effectively to hold in check these improper practices, and the more so that the desire for gain, which here forms the only motive, does not even disdain to cover itself with the mantle of pretended science."

This harsh criticism was directed at Dr. William Michaëlis, of Berlin, and was so accepted by him. It appears just as quoted in his latest pamphlet defending this theory.* His original statement of the theory in 1882 read as follows:

"When Portland cement is gauged with water, and, in consequence, hardens, a certain arrangement of the molecules takes place during, and as a result of, the absorption of the water. In the alkaline water which at once forms in the cement—many cements contain free alkali, and are in consequence quick setting—calcium hydrate separates out in a crystalline form; indeed, in the course of the hardening process, about a third of the whole quantity of lime present in the cement acts thus. The lime thus separated in crystals has very little binding action, it has rather a tendency to destroy the cohesion which the cement mass has already attained. This, however, cannot happen in good cements, because the cohesion is already too strong, and the separation of the lime takes place too gradually.

"After such a consideration of the case, it may be concluded *a priori* that if there are offered to the lime, while it is in process of separating out, pozzolanas (*i. e.*, substances which, in combination with calcium hydrate form cement), the amount of effective cement in the mortar may be increased in such a way that no more caustic lime can be deposited in crystals, but that the entire quantity of calcium hydrate becoming liberated, and which must first go into solution before it can crystallize, is employed in the formation of calcium hydrosilicate (and aluminate)."

His fuller presentation of his views in the pamphlet of 1895 before referred to reads thus:

"From this it was but a step to the conclusion that the improvement, by means of additions containing hydraulic silica, of hydraulic cements with an excess of lime must be of the very greatest importance and applicability in the case of mortars which have to be exposed to the action of sea water, because the study of the behavior of these mortars led me to the conviction that the free lime is the chief cause of the frequent failure and rapid destruction of hydraulic mortars in marine construction.

"By means of appropriate additions, the whole of the excess of lime could be securely combined, and the mortar thereby converted into one very much less capable of reaction; this would then inevitably be shown very soon and very distinctly, not merely in the degree of

* "The Behaviour of Hydraulic Cements in Sea Water," Berlin, 1895.

durability, but in the strength. Thus the behavior of the mixed hydraulic cement in sea water could not but form the truest touchstone for my theory, and also be of the highest importance from the point of view of national economy." Mr. Lewis.

"My present proposal goes at once to the root of the evil by laying hold at the outset of the injurious excess of lime, and converting it to a useful purpose; this proposal is based upon the fact which I have long upheld, that clinkered Portland cements, too high in calcic oxide and hydraulic limes, may—either in the process of manufacture or in the preparation of the mortar—be improved, and more especially rendered more capable of withstanding the decomposing action of sea water, by means of such additions as will go to form fresh hydraulic mortar with the excess of lime or with that which is set free during the hardening process, *i. e.*, with pozzolanas in the widest sense of the word. Such suitable pozzolanas are hydraulic silica itself, opal, infusorial earth, pozzolanas in the more restricted sense, trass, Santorin earth; also further, powdered glass, certain granulated blast-furnace slags, burnt alum-shale, kaolin, brick-dust, etc.

"Of all known additions of this kind, the most effective is real trass on account of the high proportion it contains of the hydraulic factors, and of the excellent quality of that portion of it which acts as sand."

Right or wrong then, whatever credit attaches to this theory of ameliorating cements belongs to Dr. Michaëlis, who since 1882 has borne the brunt of severe criticism, personal as well as technical, for the views he holds.

The strongest denials of these views have been by the German society and by M. Candlot, the well-known French authority. The reply of the German society appeared* with a note stating that it definitely closed the question. Omitting the first half of this document, the main argument reads as follows:

"It is impossible to oppose to these proofs the cases in which Portland cement has not been satisfactory in the sea. We must conclude that in these special cases there have been employed mortars which are too meager and in consequence are porous and of insufficient strength, or else that the work has been badly executed. It is certain that Portland cement cannot be held responsible for such faults.

"The Society of German Portland Cement Manufacturers has endeavored for a long time to observe the strength of limes and of cements in sea water, to enlighten its belief in this respect. At its request, and from the conviction that only tests made in the sea were capable of giving useful information, the Prussian Minister of Public Works charged the Royal Administration of the Island of Sylt with these tests. The cost was borne partly by the Ministry and partly by the association which sent besides to the Island of Sylt a commission chosen from its members. The observations were made especially on rich mortars which by reason of great strength and impermeability cause them to be less influenced than the others by mechanical effects. These tests are not yet terminated. As regards cement mortars, however, it is a fact that all the samples plunged in sea water which are

* In the *Verhandlungen des Vereins zur Beförderung des Gewerbfleisses*, 1895.

Mr. Lewis. under observation are up to the present time absolutely intact and are acquiring an increasing resistance; although, as has been remarked above, the resistance of Portland cements may be somewhat less in sea water than in fresh water. As to mixed mortars of Portland cement and lime, and especially to the mixtures of trass and lime, they are attacked by sea water.

"Michaëlis recommends the addition of trass to Portland cement intended for maritime constructions in order to render it more resistant to sea water, with the idea that the lime rendered free by the setting of cement will combine with the silica and alumina of the trass forming thus a stable compound in the presence of sea water. He has established a series of tests and obtained by the aid of an addition of trass to cement mortar a considerable increase of strength. We desire to draw attention to this fact that there is reason for distinguishing between the case in which Portland cement is mixed with another substance (in such a way that a part of the cement is replaced by an equal part of this other substance) from that in which a mortar of Portland cement and sand is completed by the addition of another substance. If the cement is replaced partially by other substances, the preceding table relative to hardening in sea water shows that the resistance is diminished, except in case of the addition of ultramarine and other substances producing analogous effects.

"If on the contrary fine powders of hydrated lime and sand within certain limits are added to cement mortar, these do produce an augmentation of strength in consequence of the filling up of the voids in a meager mortar. It is not, then, a question of the amelioration of the cement, but of the amelioration of the mortar. Trass, at the time of hardening in water, produces a more intense effect than other substances, because at the same time that it fills the voids it causes a new augmentation of density by combining with the hydrate of lime which is placed at liberty in the cement. But rich mortars which contain few voids are not ameliorated by such additions. Trass itself does not produce any improvement in them in despite of its richness in active silicic acid, because these mortars lose density by the avidity of trass for water, and the trass is unable to produce a better union of the elements of the mortar.

"In order to demonstrate the effect of pozzolana in the hardening of Portland cement, we have made some tests with trass, which is a most active pozzolana, and as Michaëlis has done, we have added the trass to cement mortar. For these tests, as the Maritime Commission of the International Congress has decided, we have especially chosen rich cements since these are to be recommended for works in the sea because of their strength and hardness; their density gives them better protection from the attacks of the sea. We have experimented in the same way nevertheless with a meager mortar, one to four. For these tests we have used sea water from the North Sea, for the reason that sulphates in solution (as the tests of Michaëlis have shown) act in a manner quite different from sea water either natural or artificial.

"The cement employed for these tests has given (for one of cement to three of sand for 28 days) a strength in tension of 318 lbs. per square inch, and in compression 3 400 lbs. per square inch. The trass came from Plaidt. The sand was sieved silicious sand. All the mortars had the same consistency. The table below gives the strengths at the end of 28 days.

Mr. Lewis.

	1	2	3	4	5	6	7	8
	1 Cem., 1 Sand.	1 Cem., 1 Trass.	1 Cem., 1 Sand, 1 Trass.	1 Cem., 2 Sand.	1 Cem., 1 Trass, 2 Sand.	1 Cem., 4 Sand.	1 Cem., 4 Sand, 1 Trass.	1 Cem., 4 Sand.
Strength in tension after 28 days.								
Fresh water.....	425	417	405	334	274	163	225	231
Sea water (N'th Sea)	417	400	394	319	307	150	216	210
Strength in compression after 28 days.								
Fresh water	4 434	4 094	4 094	3 670	3 065	1 953	1 775	2 449

"It is shown from this that rich mortars containing one or two parts of sand do not show any increase of strength in sea water by the addition of trass (columns 1 to 5). Even the mortar of one cement to one trass does not acquire greater strength than a mortar of one cement to one sand. As the single exception, the mortar of one cement, one trass and two sand does show more strength in sea water than in fresh water. It is the opposite phenomenon which is exhibited by all the others. On the other hand, meager mortar, one of cement to four of sand, has been appreciably improved and to the same extent both in fresh water and in sea water, in consequence of the addition of one part of trass (see columns 6 and 7). But we call attention to the fact that the addition of one part of fine sand to mortar one to four increases the strength in tension in the same way about 45 lbs. per square inch both in fresh water and in sea water, a fact which proves that a great part of the influence of trass is due to physical causes (a better filling of the voids).

"The strength in tension of mortar, one cement, one trass and four sand, at the end of 28 days, meanwhile, is not greater in sea water than in fresh water, although Michaëlis found it to be 128 lbs. greater in sea water than in fresh water at the end of 11 days. The disagreement is remarkable in these two contradictory tests.

"We have made some new tests with another brand of cement in mortar, one to four, which have given us the same results with or without the addition of trass. On the other hand, a mortar one to two of this cement has been improved in sea water by the addition of trass. There is reason to notice again in this table that the addition of trass caused a diminution of strength in compression—the addition of one-half a part of cement to a mortar one to four produces at least as much effect as one part trass (see columns 7 and 8)."

Mr. Candlot's argument* against the amelioration of Portland cement by silicious mixtures is as follows:

"The decomposition of mortars by the filtration of sea water or by the frequent renewal of this water in the mass of the mortar has been completely studied and its mechanism is now well understood. The researches of Messrs. Alexander, Debray, Feret and others, have very clearly demonstrated under what conditions mortars are decomposed by the passage of water, and from them we have arrived at this conclusion, that the only remedy to adopt against decomposition is to prevent the sea water from penetrating the mortar. We are led thus to dismiss the chemical reactions of sea water on mortars and to consider their action from a purely physical standpoint. Since all mortars without exception are decomposed when they are transversed by sea water, it is necessary to limit ourselves to ascertaining which are the most compact mortars, and consequently those which oppose to the passage of water the most certain obstacles. Here tests in the laboratory must be

* *Le Ciment*, Paris, September, 1896.

Mr. Lewis.

abandoned, for there is nothing to learn from them, and it is necessary to place ourselves under practical conditions in order to be able to take account at the same time of the effects of waves, of difference of temperature, etc. Tests in the laboratory have given us only one point, very important, it is true, but which might have been foreseen; this is the considerable influence of the nature of the sand; we are quite agreed to-day in giving preference to coarse sand, renouncing everywhere the use of fine sand.

"When we study the compactness of mortars, and when we seek to produce mortars as compact as possible, we easily demonstrate that Portland cement possesses in this respect a great superiority over all the other hydraulic products. In our judgment the excellent condition of cement mortars, one to one and one to two, employed at La Rochelle, and in the greater part of the works executed in all the ports of the world in the last fifty years, is due above all else to the fact that Portland cement mortar alone permits us to obtain mortars with a minimum of voids. It is, in fact, the agglomerant possessing the highest specific gravity, and the one which demands the least water for mortar making, while at the same time it is susceptible of fixing the greatest quantity of water.

"Dr. Michaëlis has recently published a study of the highest interest on the decomposition of mortars by sea water. Starting from the idea that the best resisting cements are those in which the lime finds itself engaged in the most stable combinations, he shows that Roman cements contain the least lime susceptible to reacting with sulphate of magnesia in sea water to produce the injurious salts, sulphate and sulpho-aluminate of lime. Portland cement relinquishes during hardening a certain quantity of hydrate of lime which is ready to transform itself into sulphate or sulpho-aluminate of lime. Speaking even of the lime of Teil, Dr. Michaëlis says that it ought to resist sea water better than Portland cement. Far from confirming these theoretical considerations, the facts contradict them absolutely, and make it plain that in spite of its chemical composition, perhaps less favorable, Portland cement resists much better in the sea than any other hydraulic product."

The above quotations fairly summarize the views, *pro* and *con*, on this much-discussed subject.

Mr. Belknap.

W. E. BELKNAP, Assoc. M. Am. Soc. C. E.—The writer believes that the importance of the question raised in the paper is hardly appreciated as it should be. It should be sufficient to say in respect to this that the theory and contentions of Dr. Michaëlis, which are exemplified in the paper and have been set forth in the correspondence by Mr. Lewis, are receiving the best thought and attention of cement specialists in France and Germany, and in the latter country the Minister of Public Works has formed a commission to investigate the subject fully. Dr. Michaëlis writes that the experiments under this commission "will be made in the laboratory, as well as in the sea, on large blocks," and will, he hopes, be made to extend over a period of thirty years. Dr. Michaëlis himself has recently begun a new series of experiments to extend over a period of ten years.

While there is much cement work which has stood intact for many years, there have also been grave failures, the causes for which

are enveloped in much uncertainty. Such work as the author has given is to be much commended and encouraged as being a most valuable contribution to a fund of information, the correct and final analysis of which will sooner or later discover the causes of these failures and enable engineers to determine rules for the composition and treatment of a cement to give certain assurance of its permanent durability under a certain exposure, if a cement can be made to stand it. If it cannot, the information which leads to such a conclusion is just as valuable and important to the engineering profession. Mr. Belknap.

The experiments of Dr. Michaëlis, the author and many others show without doubt that the cements used in them were incapable of resisting the action of various waters and that an admixture of certain materials did improve these cements to such an extent that they withstood the action of the same waters. There are also many practical examples of like incapability in the deterioration of large and costly structures. The writer begs to call attention to an example near at hand, in the very evident deterioration of the quay walls at the Brooklyn Navy Yard. These walls are concrete monoliths formed *in situ*. They rest on a platform, the top of which is at about the plane of low water, and rise about 5 ft. above the plane, being about 10 ft. in height. There are about 3 000 lin. ft. of this wall, which has been exposed from one to three years. The entire surface of it is pitted from 1 to 2 ins. deep and exhibits indications of further deterioration. The writer believes that what are generally regarded as the best brands of foreign and domestic Portland cement have been used in this work. From the uniformly bad appearance of this large stretch of work, one cannot escape the conviction that the cement used was intrinsically incompetent for such exposure, for there is a moral certainty that though the treatment of the cement might have been improper and negligent in some places, it would not have been so throughout the work.

On the contrary, however, and opposed to any general conclusions which might be adduced from these experiments and actual structural failures, are the many works of concrete standing intact for long periods of time. For instance, the German Society of Portland Cement Manufacturers, in its criticism of Dr. Michaëlis' work, cites the sea forts at Copenhagen built nearly forty years ago of cement of the same chemical composition as that "used by Michaëlis in the experiments from which he draws the conclusion that Portland cement is not durable in sea-water."

Also, in like corroboration, is the experience of the New York Dock Department which has built many feet of submerged concrete wall during the last twenty years. This wall, the writer is informed by competent authority, shows no signs of deterioration. It should be noted, however, that the large blocks of concrete which form the sub-

Mr. Belknap.

merged portion of this wall are hardened well in the air before being placed and may have sufficient time to acquire a protective carbonate coating which is not decomposed by the salts of sea water.

The following tables are also apparently contradictory to the results shown in Table No. 1. They are selections from some results of tests published in the report for 1895 of M. L. Holman, M. Am. Soc. C. E., Water Commissioner of St. Louis. It will be noticed that whereas the author's neat tests show an increase in strength to the end of the tests, Mr. Holman's show a loss, and whereas the author's sand tests (1 to 4) show a loss of strength after six months in all but one of the foreign brands, Mr. Holman's sand tests (1 to 3) show an increase. It may be stated on authority that in one case the same brand occurs in both sets of tables. In regard to his tests Mr. Holman writes: "The work was carefully done and represents the experience gained from a very large amount of work."

TABLE No. 7.—SHOWING RESULTS OF TESTS OF CEMENT, ONE PART CEMENT TO THREE PARTS SAND.

Average of 10 briquettes in each case. Sand between No. 20 and No. 30 sieve, one day in air, remaining time in water. Tensile strength, pounds per square inch.

	1	2	3	4
Fineness on No. 100 sieve	86.5	88.6	87.6	91.7
1 week	190 5	223.5	272.0	280.2
2 weeks	207.0	239.8	264.7	284 6
3 weeks	226.1	251.5	265.2	296.9
4 weeks	215.6	287.4	288.5	303.4
3 months	238.6	308.9	317.2	353.7
6 months	252.8	337.4	336.7	421.6
9 months	276.5	332.4	350.1	431.1
1 year	285.6	347.6	386.5	452.5
2 years	306.0	371.1	418.3	480.0
3½ years	320.3	408.7	442.0	508.0

TABLE No. 8.—SHOWING RESULTS OF TESTS OF NEAT CEMENT, MECHANICALLY MIXED, ONE DAY IN AIR, REMAINING TIME IN WATER.

Average of 10 briquettes in each case. Tensile strength, pounds per square inch.

	1	2	3	4
Fineness on No. 100 sieve	86.5	88.6	87.6	91.7
1 week	606.2	665.2	559.8	675.6
2 weeks	671.4	693.8	603.4	761.6
3 weeks	664.8	709.4	594.0	768.8
4 weeks	707.0	710.4	625.2	707.2
3 months	756.0	690.6	578.2	675.2
6 months	787.0	657.8	681.2	742.2
9 months	746.4	795.2	828.2	849.8
1 year	742.2	715.0	811.0	783.2
2 years	750.8	764.4	791.8	772.8
3½ years	655.2	750.2	672.0	689.0

TABLE No. 9.—Showing Results of Tests of Neat Cement, Hand Mixed, One Day in Air, Remaining Time in Water. Mr. Belknap.

Average of 10 briquettes in each case. Tensile strength, pounds per square inch.

	1	2	3	4
Fineness on No. 100 sieve	86.5	88.6	87.6	91.7
1 week	551.2	612 6	524 6	667.0
2 weeks	610.8	645.8	514.8	621.0
3 weeks	633.6	630.0	597.6	721.6
4 weeks	565.8	639.2	581.4	676.2
3 months	665.4	645.0	542.2	659.4
6 months	701.6	661.0	615.6	779.6
9 months	720.8	723.4	645.4	720.0
1 year	710.0	643.8	620.0	716.0
2 years	650.6	654 4	607.4	761.4
3½ years	709.0	566.4	599.2	614.8

Though the conditions under which the St. Louis tests were made are dissimilar in many respects to those of the author's tests and prohibit any comparison which would seek to make the results of Mr. Holman contradictory to those of the author, they are at variance in a large degree, and emphasize most strongly the previously cited contradictory experience as indisputable evidence of the great uncertainty which attends at present the use of Portland cement for certain purposes.

The writer's experience is in accordance with the theory of Dr. Michaëlis that a large part of the lime is set free during the hardening process and must be finally washed out or taken into combination with external salts. This fact does not seem to be disputed by any of the authorities who have made careful inquiry on the subject. What becomes of it and in what degree its presence in a loose state in the mortar (together with alumina when exposed to sea water) affects the integrity and durability of a cement structure under water is the main point in dispute, in regard to which present testimony is somewhat conflicting.

Whether trass is a necessary admixture to guarantee Portland cement permanently against certain exposures does not yet seem to have been fully determined, though the following statements, which are found in the criticism of Dr. Michaëlis' work made by the German society previously mentioned, seem to favor a conclusion in that direction.

"It cannot be denied that a correct idea lies at the bottom of this theory (of the possibility of improvement).

"Trass acts, particularly in hardening in water, more favorably than other substances because, besides this filling of the interstices, a further condensation of the mortar takes place, through the combination of the trass with the lime separating out from the cement."

Mr. Belknap.

The writer believes the present results of this investigation show that it is much safer to use for sea-water work a cement of low comparative strength in which the basic compounds are comparatively low in proportion to the acid compounds, than to use one of high strength in which the basic compounds are comparatively high. This is simply a preference for future durability over initial strength. He is not, however, of the opinion that such a cement when free from deleterious ingredients will not make durable mortar (in sea water) when mixed in rich proportions, say one to two. The investigation of this subject promises, however, to show how it is possible to make a poorer, therefore cheaper, mortar durable under the same exposure.

In view of the presentation by Mr. Lewis, in his discussion, of the criticism made by the German Society of Portland Cement Manufacturers of Dr. Michaëlis' work on "The Behaviour of Hydraulic Cement in Sea Water," the writer begs to call attention to some extracts from the reply made by Dr. Michaëlis to the same, in which he shows how the association has misinterpreted the results of its own experiments and presents the results of further tests in support of his theory. He says:

"I may remark that the strength of Portland cement *per se, i. e.*, of neat Portland cement mortar, is quite of minor importance, and that the strength is not the only important property of cement, that its soundness and durability are even of greater importance. Is it not possible to improve Portland cement without increasing its strength? I affirm that Portland cement can be improved even at the expense of the latter. I proceed now to the examination of the results of the experiment given in Table II (Table No. 10), with which, strange to say, the Board seeks to support its assertion that a practically applicable pozzolana, such as trass, cannot produce an improvement."

The writer inserts here the table as it appears in the criticism of the association with the explanations concerning it.

TABLE No. 10.—PREPARED BY THE GERMAN SOCIETY OF PORTLAND CEMENT MANUFACTURERS.

	1	2	3	4	5	6	7	8
Kind of Hardening....	1 part cement ..... 1 part sand.	1 part cement 1 part trass	1 part cement 1 part trass 1 part sand	1 part cement ..... 2 parts sand	1 part cement 1 part trass 2 parts sand	1 part cement ..... 4 parts sand	1 part cement 1 part trass 4 parts sand	1.5 pts. cement ..... 4 parts sand
TENSILE STRENGTH AT 28 DAYS.								
In fresh water.....	425	419	405	334	275	164	225	230
In sea water.....	419	400	395	319	308	151	216	210
COMPRESSIVE STRENGTH AT 28 DAYS.								
In fresh water.....	4 454	4 111	4 111	3 686	3 079	1 961	1 783	2 469

"The cement used in the experiments yielded the normal tests one cement to three sand, after 28 days a tensile strain of 320 lbs., and a compressive strain of 3 411 lbs. per square inch. The trass employed

came from Plaidt, the sand was quartz sand, retained between the sieves with 380 and 5 800 meshes per square inch respectively.* All mortars were made of the same consistence." Mr. Belknap.

Dr. Michaëlis says:

"In this series of experiments, one of the essential factors for forming a judgment on the matter is unfortunately absent, *i. e.*, the density of the test briquettes; it is only stated that the briquettes are made of the same consistency. But in order to form a mortar out of 1 part cement and 1 part sand of the same consistency as a mortar of 1 part cement and 1 part trass, twice the quantity of water is required with the trass mixture as with the sand mixture; thus, while for the latter one uses about 12 parts of water to 100 dry substance, 24 parts would have to be used with the trass mixture. Furthermore, if we consider that the air-dried genuine trass contains 8% of water, then we have in the sand mixture 12, and in the trass mixture 28 parts water. In consequence of this the sand mixture yields 10 volumes against the trass mixture's 13 volumes.

"If, in spite of this very significant difference in the density of the briquettes, about 2.50 against 2.25,† the trass mortar No. 2 turns out almost as strong as the sand mortar No. 1, then, clearly, a considerable improvement can be recognized as having been effected even in strength; and it cannot be looked upon as strange, or in any way favorable to the opinion of the Board, that the compressive strengths of the trass mixture have turned out lower than those of the so very much denser cement and sand mixtures.

"In all the following mixtures, though less in the same ratio as the proportion of sand increases, the same disadvantage attaches to the trass mixtures; all these contain much more water, and are thus much less compactly made. For example, the mortar No. 3 required 17 parts water (+ 2.7 from the air-dried trass) making nearly 20 parts water, against the mortar No. 4 with only 9.5 parts water. Trass can only harden hydraulically with quicklime; either trass is active as an addition to Portland cement, and then only with the help of the lime separating out from the cement, or it is inactive, and in this case behaves only as so much sand, and even then only as inferior sand from the quantity of clayey matter it contains.

"If we look now at the results of experiments 3, 5 and 7, in comparison with 4, 6 and 8, and if we consider the trass an inactive addition, then No. 3, a mixture of 1 part cement with 2 sand, in spite of its much smaller density, is almost as strong as No. 1 made from 1 part cement and 1 sand; No. 5, a mixture of 1 part cement and 3 sand, almost as strong as No. 4, a mixture of 1 part cement and 2 sand; No. 7, a mixture of 1 part cement and 5 sand, about 50% stronger than No. 6, which is a 1 to 4 mixture; and No. 7 stronger than No. 8, although the latter contains only $\frac{5}{7}$ as much sand as No. 7.

"In each case it is shown how strong the action of trass is already at 28 days.

"And, moreover, it is surely not to the disfavor of the trass mixtures that they produce more mortar.

"That the purely physical increase of strength, which arises from

* "Sand of this grain has been adopted for sea-water experiments by the International Conference because it furnishes a denser mortar, more suitable for marine buildings than coarse sand, and is used likewise in the experiments on Sylt. Michaëlis has used normal sand in his present experiments, with the object of testing porous mortar, which contains a large amount of interstitial space."

† The direct experiment gave the densities to 2.370 and to 1.914—far greater than had been supposed.

Mr. Belknap. the condensing of the cement mortar by addition of fine sand or similar powdered substances to coarse sand (standard sand, for example), can only be very trifling, every expert must know, and that an increase of strength by two- or three-fold can never be produced by this means. Even in spite of this fact, the objection has been raised against my work that I had not brought testimony, that the observed improvement was not entirely attributable to the pulverulent nature of the trass. Although I have again and again demonstrated for 20 years within what limits a physical improvement can occur (I refer also to my report to the London Chamber of Commerce, Cement Section, in 'Engineering,' 5th June, 1896, p. 753), I have begun a new series of experiments, to stretch over ten years, which must convince every doubter. In these experiments were used:—

"(A.) Portland cement, 'Star' brand, of following composition: Silica, 23.027%; alumina, 6.249%; iron oxide, 2.450%; lime, 63.233%; magnesia, 0.916%; potash, 0.660%; soda, 0.069%; sulphate of lime, 2.744%; water and carbonic acid, 0.691%; insoluble, 0.210%; total, 100.249 per cent.

"(B.) The same trass as indicated in my treatise on the 'Behavior of Hydraulic Cements in Sea Water,' and sifted, likewise, through the 76 sieve.

"(C.) Berlin (Freienwalder) standard sand.

"(D.) Fine washed Freienwalder sand, of which

11.4%	passes the sieve with	32 000	meshes	to the	square inch.
16.8 "	" "	16 000	"	"	
10.4 "	" "	10 000	"	"	
45.4 "	" "	6 000	"	"	
16.0 "	" "	2 500	"	"	

"With these materials the following mortar mixtures were made and gauged into briquettes, which, after 24 hours' hardening in air saturated with moisture, were immersed, part in ordinary water, part in artificial sea water, as specified in my treatise. The sea water treatment was conducted in exactly the same way as was indicated in my first work, only I now allow the briquettes to stand dry for 24 hours each time after the sea water has been run off; by this means they are allowed to drip thoroughly, and the fresh sea water can more easily penetrate them.

"The testing periods from the day of immersion are fixed at 28 and 90 days, 1, 2, 3, 4, 5, 6, 8 and 10 years.

N.	1 part by weight	"	"	'Star' cement standard sand	9.5 water to 100 dry material
O.	1	"	"	'Star' cement	10.1 water
	1	"	"	trass	to
	6.2	"	"	standard sand	100 dry material
P.	1	"	"	'Star' cement	9.8 water
	1	"	"	trass	to
	8	"	"	standard sand	100 dry material
Q.	1	"	"	'Star' cement	10.0 water to 100 dry material
	1	"	"	trass	
	1	"	"	fine sand	
	7	"	"	standard sand	
R.	1	"	"	'Star' cement	9.3 water
	1	"	"	fine sand	to
	7	"	"	standard sand	100 dry material

S signifies 'fresh water hardening.'
M " 'sea water hardening.'

Mr. Belknap.

"The numbers represent pounds per square inch, tensile strength; the second row in each period, pounds per square inch, compressive strength (obtained from the tensile briquettes bound together again after breaking).

"Up to the present the results of the first three periods, 28, 90 and 180 days, are forthcoming.

Age.	N		O		P		Q		R	
	NS	NM	OS	OM	PS	PM	QS	QM	RS	RM
28 days.....	223	182	266	334	184	269	189	270	83	79
90 days.....	306	220	338	427	269	325	277	334	119	111
" "	3 086	2 700	3 714	4 343	2 357	2 557	2 800	3 300	874	963
" density....	2.199	2.242	2.236	2.276	2.177	2.194	2 224	2.244	2 134	2.177
180 days.....	310	249	394	452	306	378	310	384	126	143
" "	3 314	2 900	3 871	4 430	2 614	3 043	3 085	3 543	957	1 000
" density...	2.191	2.259	2.238	2.287	2.198	2.217	2.240	2.262	2.142	2.187

"These numbers cannot be misunderstood. Above, the supposition was made that trass be chemically inactive, and only act as so much inferior sand in order to lead *ad absurdum* through the results of the experiments of the Board, and asserts that the additions do harm in proportion to their amount. Now trass may be considered as cement, in order to point out the error of those who reckon half the quantity of Portland cement as more effective than trass.

"On the supposition that trass equals cement, the mixtures P and Q are like N, 1 part cement to 4 sand, but P and Q are, even at 28 days, about 50% stronger in tensile strength, and at 90 days Q is also much stronger in compressive strength in the case of the briquettes exposed to the action of the sea water.

"In the case of P, the compressive strength is not superior to that of N only because the P briquettes were made less dense than the N briquettes.

"The tensile tests show, as is seen, the influence of the sea water much more distinctly than the compressive tests, and this is because, with the separation of salt—chiefly calcium-alumino sulphate and not mere magnesium hydrate—causing ultimately the destruction of mortar, there results first a condensing of the mortar which, for a time, increases the compressive strength, till the bursting of the cohesion, the blowing, and therewith the disintegration of the mass take place.

"What the purely physical improvement by addition of fine to coarse sand can amount to, a glance at the mixture R in comparison with P and Q will show.

"I have pointed out that under certain favorable circumstances Portland cement can resist the action of sea water, but that only dense, rich, and therefore expensive, cement mortars can have by chance any permanent durability. I profess to produce, on the other hand, poor and cheap durable mortars out of Portland cement and pozzolana, and I am convinced that this is a matter of great importance, and worthy of all consideration.

Mr. Belknap. "Even if the poor mortars, mixed according to my suggestion, could not withstand the washing out sufficiently long, still much would be gained by the fat impermeable mortar becoming chemically quite durable on the one hand, and much cheaper on the other. The suggestion that through the closing of the pores (colmatage) a protection is formed, as has hitherto been accepted, is a delusion. If this closing of the pores, as is supposed, were caused only by the separated magnesium hydrate, then, doubtless, a favorable effect might be expected from it; but I have found that the separation in the pores, or better, in the mortar mass, under the influence of sea water on hydraulic cement, especially with Portland cement, consists in the main of the destructive agent—calcium sulphate + calcium aluminate – as was but to be expected.

"What surety have we that this separation has only a favorable effect, stopping just as it has increased the density of the mortar, and that it does not proceed farther to destroy the cohesion, break up the mortar, and reduce it to mud? Clearly none; but everything is here left to chance. The proposed mixing of cement and trass, or other valuable pozzolanas, prevents a dangerous reaction with the sea water, and the excessive separation of salts in the substance of the mortar; the stoppage of the pores need not be counted upon with my mortar mixtures."

With respect to the treatise of Dr. Michaëlis, referred to by Mr. Lewis, the following quotations from a letter from Dr. Michaëlis will alter some impressions which might naturally be given by his paper, and also add to the information on this subject:

"At first, I wish to say that I have not at all recommended Roman cements for sea structures; certainly the chemical properties make the best and uniform Roman cements more fitted to withstand the chemical action of sea water; but Roman cements are rarely uniform, and their physical qualities are very inferior to Portland cements. Only the best chemical and physical qualities combined will secure the durability of mortars in sea water. I wish to utilize the high physical qualities and the uniformity of Portland cements, but to improve their chemical deficiency—the over-limed constitution—by adding the very best pozzolanas or hydraulic silicic acid in its densest state. I therefore have recommended for sea structures the mixture of Portland cement with trass (volcanic tufa) or Santorin earth. * * *

"If you will employ one of our best Portland brands * * * combine it with trass or Santorin earth, and take instead of 100 parts by weight of Portland cement, 50 parts cement and 50 parts trass (through the No. 80 wire gauge sieve 900 meshes per square centimeter, equal to 6 000 per square inch), or 60 cement and 40 Santorin earth (same fineness), with such mixtures of hydraulic substances, the sea water can no longer form large quantities of the terrible double salt (the aluminate of lime and sulphate of lime) which crystallizes with 60 or more equivalents of water. The strength and tightness of your mortar compositions are beyond doubt; but take coarse sand, with only 20 to 30% of fine sand in it." * * * "I am not sufficiently acquainted with your genuine American brands; * * * if these are not richer in alumina than the above-mentioned cements, you may use them; but no better Portland cement for sea structures than * * * such brands which contain only 5 to 6% of alumina."

* * * * * * * *

"If you will try trass you must take it in the form of tufa which will bear little duty,* I suppose, and grind it yourself, and the Santorin earth from Fium, in the state of so-called Greek earth. * * * Mr. Belknap.

"1 cu. m. Santorin earth, or about 700 kilos., will cost at Santorin ..... $2 25 to 2 50
1 ton, 1 000 kilos. trass, on the Rhine..... 4 00
1 cu. m. tufa, 650 kilos..... 2 50

With respect to the discussion of Mr. Lesley, the following from another letter of Dr. Michaëlis is pertinent:

"I am not of the opinion of those who accept that by elevating the amount of lime in Portland cement from 1 (silicate) to 2 (lime), in former time to 1 to 2.2 (the average is lower than 2.1), all the failures of modern cement-mortars in sea structures sprang up and may therewith be easily interpreted; certainly the more lime contained in the cement, the more of this body becomes free during the hardening process, and can react with the salts of the sea water, but, first, the strength of the cement increases with the amount of lime, its cohesion or resistance against expansives is stronger; second, with increasing the lime the amount of alumina diminishes, in consequence of that only a smaller amount of the noxious double salt (aluminate and sulphate of lime) can be formed. You see circumstances exist which may compensate themselves. I do not assume that before 1880 the cements have been safer, on the contrary."

The author has given the writer the following analysis of the cements used in his experiments, which information will be valuable in an interpretation of his results:

	a	*b*	*c*	*d*	*e*	*f g h i*
Silica	23.32	20.72	27.18	21.58	25.40	22.5
Alumina and oxide of iron	8.97	11.31	8.11	11.55	6.98	11.7
Lime	63.50	62.73	59.50	60.21	63.91	59.5
Magnesia	0.97	2.13	1.41	1.01	.....	0.9
Sulphuric acid	1.43	0.86	0.99	1.50	1.37	2.85
Residue from silica after treatment with hydrofluoric and sulphuric acids	0.55	0.20	0.74	0.90	0.18	0.40

Moisture, carbonic acid and alkalies not determined.

ANDREAS LUNDTEIGEN, Esq.—It was the author's object to present briefly his own observations, which apparently corroborate the observations of others, to the effect that most Portland cements, however excellent in qualities such as fine grinding, high tensile strength, etc., and however well fitted for use in air and apart from the continuous action of water, are by no means to be relied on in water, especially sea water and water containing sulphates; but that these same cements when mixed with extremely fine silicious materials, such as sil, will, in such waters, give an excellent and fully reliable mortar and consequently concrete, taking it for granted that the aggregate is all right. The author's experiments were not started with the view of publishing Mr. Lundteigen

* The writer was charged no duty on 200 lbs. of trass imported from Andernach.

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them, but simply for his own satisfaction; and this is the reason why the tables of tests were not planned more systematically.

The sand used was clean, natural bank sand, screened as explained, but not washed. The same sand was used for all tests as stated in the paper; it is important to know whether the failure of the sand briquettes was due to the sand or some other cause and to know the remedy; it is the opinion of the author that the sulphates in the water were the cause.

The author said that "it becomes apparent from an inspection of the sand tests in Table No. 1, that those briquettes which broke the highest in a short time fared worst in the long run, and analysis shows that those cements contain more basic elements, lime and magnesia, in proportion to acid elements, silica, alumina and oxide of iron, than the other samples." The first five samples in the sand test in Table No. 1 broke higher at 7 and 28 days than the four last samples, but they were in much the worst condition at the end of two years.

It will be seen from the author's table of analysis quoted by Mr. Belknap that the proportions between the basic and acid elements are as follows:

$$\frac{CaO + MgO}{SiO_2 + Al_2O_3 + Fe_2O_3} = \underset{1.996}{a} - \underset{2.025}{b} - \underset{1.726}{c} - \underset{1.848}{d} - \underset{2.005}{e} - \underset{1.766}{\underbrace{fghi}}$$

The magnesia in sample *e* was not ascertained, but for the sake of comparison is assumed to be 1.0 per cent. Each of the samples *f*, *g*, *h* and *i*, were not analyzed, but were known to be very nearly the same and as previously given. If the sulphuric acid be classed as an acid element then:

$$\frac{CaO + MgO}{SiO_2 + Al_2O_3 + Fe_2O_3 + SO_3} = \underset{1.912}{a} - \underset{1.972}{b} - \underset{1.676}{c} - \underset{1.768}{d} - \underset{1.923}{e} - \underset{1.630}{\underbrace{fghi}}$$

It would at first seem as if there is not enough harmony between these analyses and the tests to warrant the author's statement, but when it is recalled how many things besides the chemical composition influence the quality and the testing of Portland cement, some reason for the assertion may be granted.

$$\left.\begin{array}{l}\text{The residue from the silica after}\\ \text{treatment with hydro-fluoric}\\ \text{and sulphuric acid.....}\end{array}\right\} = \underset{0.55}{a} - \underset{0.20}{b} - \underset{0.74}{c} - \underset{0.90}{d} - \underset{0.18}{e} - \underset{0.40}{\underbrace{fghi}}$$

From this it may be safely inferred that less of the clay-substance (acid elements) has, in the process of burning, been acted upon by the lime in samples *c* and *d* than in the other samples, and that such good results should not be expected from these two samples as would otherwise be looked for. All nine samples, however, represented good Portland cement, and swelling or cracking would not occur in pure

water. If these samples had been overlimed, in the usual understanding of the word, or otherwise faulty, then the author would have expected to see the swelling or cracking first in the neat briquettes; as it is, it comes from without, that is, from the contact between the sulphates in the water and the hydrate of lime in the mortar. Thus it can be seen why the sand briquettes, being the most porous, disintegrate first, and why the disintegration first appears at the corners of the briquettes; it also explains why actual masonry, on account of its size, resists the action of such waters longer than do small test bodies; besides masonry as a rule is made as compact and as impenetrable to the water as possible. If the sil or other finely divided silicious material did nothing else but help to fill out interstices and make the mortar or concrete impenetrable by water, it would be of much value; but, besides that, it is, at temperatures above 60° Fahr. at least, able to combine directly with the hydrate of lime and thus become a part of the cementing substance, which fact the following one- Mr. Lundteigen

TABLE No. 11.

	Tensile Tests.		Compression Tests.		
	1 cement. 3 sand.	1 cement. 1 sil. 6 sand.	1 cement. 3 sand.	1 cement. 1 sil. 6 sand.	
28 days.....	212	78	1 316	451	The author is aware that the compression tests are proportionately low (the briquettes only 1-in. cube), but they will serve for comparison.
6 months..	321	144	1 927	1 125	
12 " ..	581	218	more than 2 030	1 155	

year tensile test clearly illustrates. Composition, one part slacked, lime, two parts sil, six parts sand; strength after seven days in air and the remaining time in water, 259 lbs.; strength after remaining all the time in a sealed glass jar, 275 lbs.

The water used for all the tests mentioned in the paper was the same, and the author can see nothing contradictory between the tests given in the different tables. The cement used in Tables Nos. 2 and 3 was the same brand as represented by *f*, *g*, *h* and *i* in Table No. 1. The neat, as well as the cement and sand, tests cover only eleven months, so that a decrease in strength could not reasonably be looked for. In Table No. 4 the German cement is the same as *b* in Table No. 1, and the decrease in strength of the sand briquettes between eighty days and twelve months is even more marked than in Table No. 1, because the briquettes were smaller (1-in. cubes) and thus more easily acted on by the water.

The briquettes for each table of tests were made very carefully and

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as far as possible under the same conditions, but the author admits that an average of three breakings is not enough for very accurate results.

The water is neutral to litmus.

At the request of Mr. Maclay the author gives the tests in Table No. 11. Briquettes kept in air all the time.

This table would indicate that no benefit can be obtained by silicious admixtures when the mortar is to remain in air only. Neither would any improvement in this case be called for, as the author has heard of no instance where good Portland cement has failed when exposed to the air only or when guarded from the continuous action of water.